Measuring the returns to innovation (1)

Prof. Bronwyn H. Hall

Globelics Academy

May 31/June 1 2004

Outline

Today

1. Overview – measuring the returns to innovation
2. Measuring the returns to R&D using productivity regressions
3. Measuring the private returns to R&D using market value equations

Tomorrow

1. Measuring innovation using patent data
2. Innovation survey data

Why is this an interesting problem?

- To economists
  - Test models of innovation and growth, e.g., are there spillovers?
  - Advise policy makers
- To managers
  - Allocation of resources for invention
  - Measure results of innovation
- To accountants
  - Accurate reporting of intangible value in company accounts
- To policy makers
  - How to increase innovative activity?
  - How much to spend; what policy instrument to use? How to choose the level of subsidy?
  - Evaluation of results of policy

Framework

- Investment in innovation (R&D, training, etc.) creates an asset which pays off in the future
  - At the firm (enterprise) level, asset tends to become less productive over time (it depreciates)
- At the industry/country/world level, individual investments in innovation create an aggregate “knowledge” asset
  - Aggregate knowledge depreciates more slowly
  - Even when private firms no longer earn returns from an innovation, the knowledge they have created remains useful

Overall framework

- Innovation investment R at time $t = R_t$
- Innovation asset $K_t = f(R_t, R_{t-1}, R_{t-2}, \ldots)$

Gross rate of return $\rho \equiv \dfrac{\partial PDV(\pi(K_t))}{\partial K_t} \dfrac{\partial f(R_t, R_{t-1}, R_{t-2}, \ldots)}{\partial R_t}$

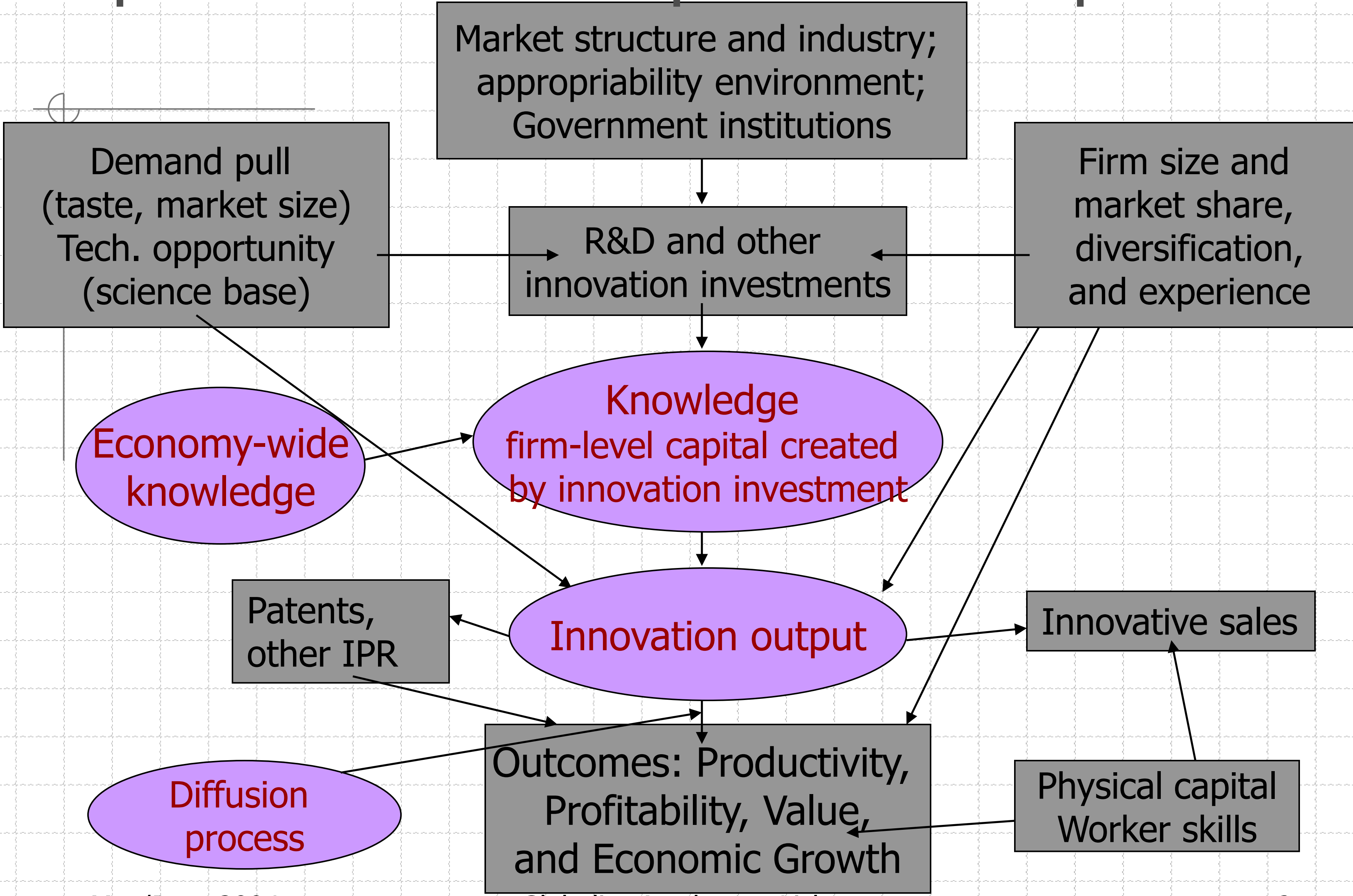
Net rate of return $\equiv \rho - \delta$

where PDV = present discounted value

δ = depreciation of innovation assets

$\pi(K)$ = profits or welfare given K

Map of innovation inputs and outputs



Input measures

- R&D spending
  - within firm
  - alliance and joint venture participation
- Purchase of new capital equipment
  - important for small firm innovation
- Technology purchases/licensing
- Marketing related to new products
- Training and education of workers
- Spillover variables
  - Based on geography or technology
- CIS variables
  - Whether a firm is "innovative"
  - Sources of knowledge – suppliers, partners, consumers, internal

Intermediate inputs/outputs

- Patent counts
  - Raw
  - Weighted by citations received
- Innovation/new product counts
  - From news journals
  - From surveys
- CIS – shares of sales that is
  - New to market (radical?)
  - New to firm (incremental?)

Output measures

- Individual innovations
  - Licensing fees
  - Patent renewals as a function of fee schedule (Schankerman-Pakes)
  - Surveys (Harhoff, Scherer, Vopel)
- Firm level
  - Profits or revenue productivity (not intertemporal)
  - Stock or financial market value - covers a broad range of technology & industry, but requires active stock market (Griliches, Hall, etc.)
- Economy level (social returns)
  - Consumer willingness-to-pay (Trajtenberg)
  - Aggregate productivity growth (Griliches, etc.)

Relating inputs and outputs

1. Production function approach – private and/or social returns
2. Market value approach – private returns
3. Patents as indicators of innovation activity
4. Using innovation surveys

1. Production function framework

- Cobb-Douglas production (first order log approximation to production function)
- Line of business, firm, industry, or country level
- Variety of estimating equations:
  - Conventional production function
  - Partial or total factor productivity function
  - R&D intensity formulation
  - Semi-reduced form (add variable factor demand equations)

Conceptual issues

- What is output?
  - Conventional measures exclude much of the benefit of government R&D – space, defense, environment, health
  - Unmeasured quality change and new goods
  - Revenue or output?
- What is knowledge capital?
  - Varying lags in producing knowledge
  - Depreciation is endogenous at the firm level
  - Own capital depends on the efforts of others as well as the firm itself (spillovers)

Productivity approach (1)

$$Y = AL^{\alpha} C^{\beta} K^{\gamma} e^{u}$$

where L = labor

C = capital

K = research or knowledge capital

u = random shock

$$K_t = (1-\delta)K_{t-1} + R_t$$

Productivity approach (2)

Take logarithms and model the intercept with year and firm (or industry) effects:

$$y_{it} = \eta_i + \lambda_t + \alpha l_{it} + \beta c_{it} + \gamma k_{it} + u_{it}$$

$$i = 1, \ldots, N \qquad t = 1, \ldots, T$$

Econometrics:

- The error u may possibly be correlated with the current (and future) input levels.
- The firm effect η may also be correlated with input levels.

Alternative formulations

Differencing to remove firm effect:

$$\Delta y_{it} = \Delta\lambda_t + \alpha\Delta l_{it} + \beta\Delta c_{it} + \gamma\Delta k_{it} + \Delta u_{it}$$

R&D intensity version:

$$\Delta k_{it} = \frac{R_{it} - \delta K_{i,t-1}}{K_{i,t-1}} \cong \frac{R_{it}}{K_{i,t-1}} \quad \text{if depreciation } \delta \text{ is near zero}$$

$$\Rightarrow \gamma\Delta k_{it} \cong \left(\gamma \frac{Y_{it}}{K_{it}}\right)\frac{R_{it}}{Y_{it}} = \rho\frac{R_{it}}{Y_{it}}$$

where $\rho = \dfrac{\partial Y_{it}}{\partial K_{it}}$, the gross rate of return to R&D capital

Alternative formulations

Partial or total factor productivity:

$$\text{Partial: } \Delta y_{it} - \hat{\alpha}\Delta l_{it} = \Delta\lambda_t + \beta\Delta c_{it} + \gamma\Delta k_{it} + \Delta u_{it}$$

$$\text{Total: } \Delta y_{it} - \hat{\alpha}\Delta l_{it} - \hat{\beta}\Delta c_{it} = \Delta\lambda_t + \gamma\Delta k_{it} + \Delta u_{it}$$

Where α and β may be estimated using factor shares at the firm level (when available).

This approach often combined with the R&D intensity approach.

Note the change in the assumptions on u required for consistency.

Some measurement issues

- Often we have only sales, and not value added nor materials
  - Assume materials share constant across time for each firm
  - Result is that coefficients are inflated by (1-share of materials) – confirmed in practice
- Double counting of R&D (Schankerman 1981)
  - R&D expenditure is also in labor and capital
  - Under simple assumptions, elasticity is downward biased by share of R&D in growth of labor/capital
- Effects of choice of deflators (input and output)

Simultaneity

- Sources of endogeneity:
  - Inputs and output chosen simultaneously; favorable productivity experience leads to increased R&D effort in the future
  - Firm knows its efficiency level (fixed effect) when choosing inputs
  - Inputs measured with error
- Solutions
  - Difference to remove fixed effect, exacerbates measurement error bias
  - Total or partial productivity moves some inputs to left hand side
  - Instrumental variables, in particular GMM for panel data

French Firms 1981-1989

	Sales vs Value added		
Dep var	Log S	Log VA	(1-.74)*VA Coeff
Log C	.043 (.002)	.193 (.008)	.050
Log K	.024 (.001)	.092 (.004)	.024
Log L	.193 (.005)	.699 (.012)	.183
Log M	.735 (.004)	--	
Sum	0.995	0.984	0.257
R^2	.993	.926	
s.e.	.115	.349	

Source: Mairesse and Hall 1999

197 French firms 1980-1987

Pooled OLS estimates

	Double counting		Partial Productivity	
	Unadjusted	Adjusted	Labor share = 0.67	Labor share estimated
Log(C/L)	.21 (.01)	.20 (.01)	.11 (.01)	-.05 (.02)
Log(K/L)	.18 (.01)	.25 (.01)	.22 (.01)	.49 (.02)
logL	-.03 (.01)	-.04 (.01)	-.00	.10
R^2	.996	.996	.998	.974
s.e.	.336	.344	.347	1.234

Source: Hall and Mairesse 1995

French Firms 1981-1989

	Dep Var = log(Y/L)			
	Total	Within	Long diff.	First diff.
Log C/L	.20 (.01)	.17 (.06)	.20 (.13)	.23 (.09)
Log K/L	.25 (.01)	.07 (.03)	.13 (.03)	.05 (.07)
Log L	-.04 (.01)	-.06 (.05)	.17 (.12)	-.60 (.10)
R^2	.996	.103	.030	.183
s.e.	.344	.186	.051	.193

Source: Hall and Mairesse 1995

Note: all estimates are inconsistent if RHS vars not strictly exogenous; within are probably least biased.

Approximate rate of return

$$\frac{\partial Y}{\partial R} = \gamma \frac{Y}{R}$$

Large R&D-doing manufacturing firms

Country	Y	R/Y	γ	dY/dR
France (1981-1989)	VA	4%	.069	1.72
UK (1988-1996)	Sales	2.42%	.065	3.30
Germany (1988-96)	Sales	5.84%	.079	1.35
US (1990-1998)	Sales	8.00%	.118	1.48
Chile (1998)	VA	1.5%	.131	*8.7*

Output deflation at the firm level

Interpreting productivity growth regressions at the firm level:

$$(1)\ \Delta y_{it} = \Delta\lambda_t + \alpha\Delta l_{it} + \beta\Delta c_{it} + \gamma_Y \Delta k_{it} + \Delta u_{it}$$

versus

$$(2)\ \Delta s_{it} = \Delta y_{it} + \Delta p_{it} = \Delta\lambda_t + \alpha\Delta l_{it} + \beta\Delta c_{it} + \gamma_S \Delta k_{it} + \Delta u_{it}$$

If (2) is estimated instead of (1), we obtain an estimate of

$$\gamma_S = \gamma_Y + \gamma_P$$

The *revenue* productivity of R&D is the sum of

- *true* productivity of R&D
- the effect R&D has on the prices at which goods are sold (due to quality improvements, product differentiation, and cost reduction)

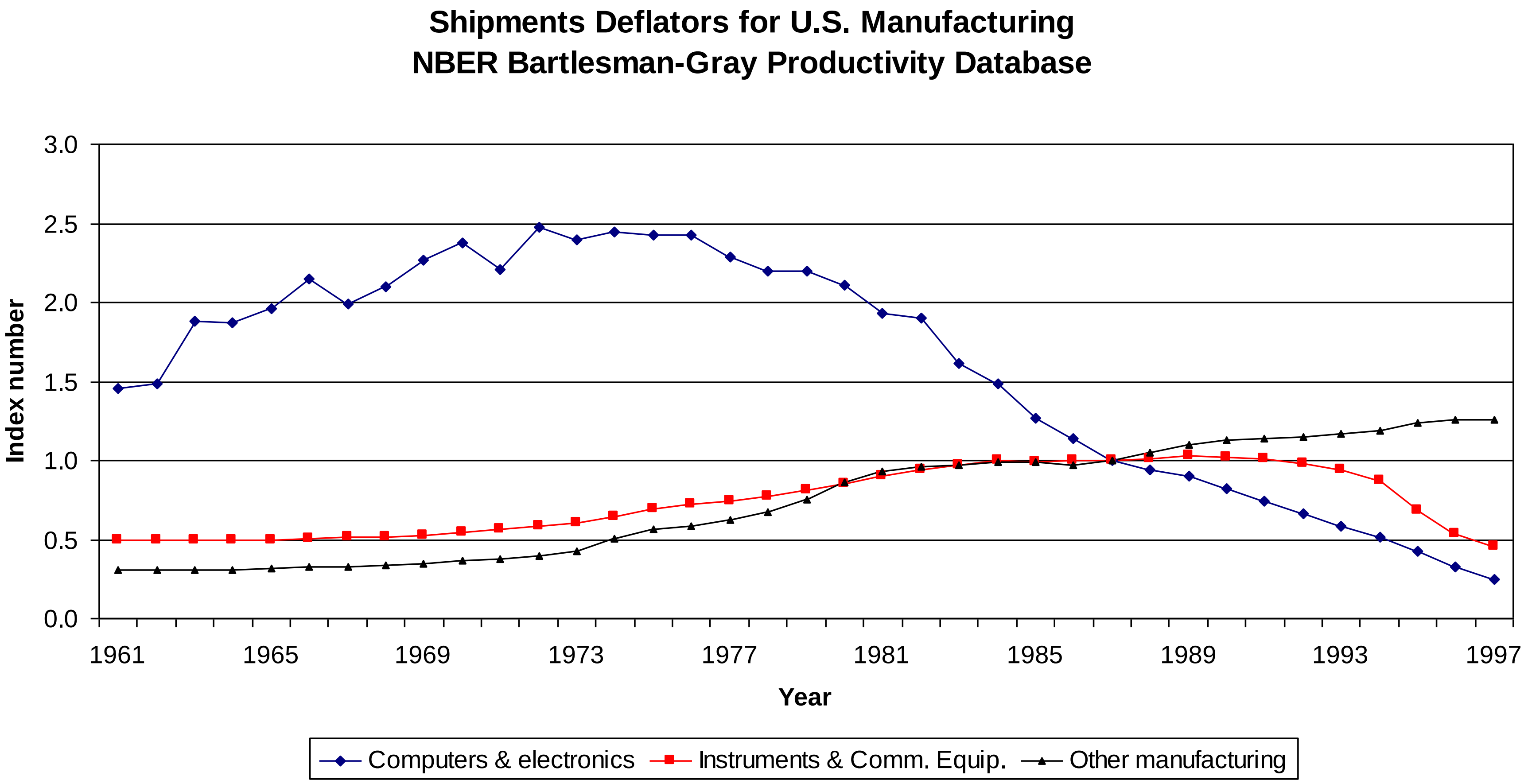
Interpretation

- Revenue productivity is a determinant of private returns
- True productivity (more constant quality output for a given set of inputs) is relevant for social returns
- The difference represents pecuniary externalities
  - benefits received by downstream producers and consumers in the form of lower prices
  - in some cases, these can be large

Illustration

- Some U.S. deflators at the industry level are hedonic, notably those for the computer industry and now the communications equipment industry (see next slide)
- Deflate firm sales by 2-digit deflators instead of one overall deflator
- Result: true productivity is substantially higher than revenue productivity, because of hedonic price declines in these R&D-intensive industries

Hedonic Price Deflator for Computers



Estimated R&D Elasticity – U.S. Manufacturing Firms

Period	Dep. Var = Log Sales (S)	Dep. Var = Log Sales, 2-digit deflators (Y)	Difference ("price effect") (P)
1974-1980	-.003 (.025)	.102 (.035)	-0.099
1983-1989	.035 (.030)	.131 (.049)	-0.096
1992-1998	.118 (.031)	.283 (.041)	-0.165

Method of estimation is GMM-system with lag 3 and 4 instruments. Sample sizes for the three subperiods are 7156, 6507, and 6457.

$$\gamma_S = \gamma_Y + \gamma_P$$

Firm stock market value

- Measurement of *private* returns to investment in innovation

Why market value?

- Returns to innovation are the profits earned in the future from investments made today
- Firm value on financial markets is a forward looking measure, allows intertemporal production of innovations
  - Under an efficient markets assumption, equal to the expected value of the discounted cash flows that will be received in the future from the assets of the firm
- Observable for a wide range of firms and countries (although not as wide as we would like)
- Measuring intangible assets a present-day problem for economists and accountants
  - Exploring this methodology helps our understanding of how to measure innovation assets

Theoretical framework

- Measured market value = value function associated with firm's profit-maximizing dynamic program
- References
  - Hayashi (Econometrica 1982) – conditions under which marginal = average Q (including taxes)
  - Wildasin (AER 1982) – same thing for multiple capitals
  - Hayashi & Inoue (Econometrica 1991) – same model with capital aggregator function

Theoretical Q model

- Tobin’s original Q = ratio of the market value V of a (unique) asset to its replacement cost A
  - Q>1 => invest to create more of the asset
  - Q<1 => disinvest to reduce asset
  - Q=1 in equilibrium
- Hayashi (1982) - the asset is a firm
  - derived Q from the firm’s dynamic program
  - gave conditions under which marginal Q (dV/dA) equal to average (V/A)
- Hayashi-Inoue (1991) and Wildasin (1984)
  - developed the theory with more than one capital
  - See Hall 2004 for application here

Practice: hedonic regression

$$V_{it}(A_{it},K_{it}) = b_t\,[A_{it} + \gamma K_{it}]$$

Linear approx: $\log V_{it} - \log A_{it} = \log Q_{it} = \log b_t + \gamma\, K_{it}/A_{it}$

Non linear: $\log Q_{it} = \log b_t + \log(1+\gamma_t K_{it}/A_{it})$

$Q_{it} = V_{it}/A_{it}$ is Tobin's q
b_t = overall market level (approximately one)
K_{it}/A_{it} = ratio of intangible innovation assets to tangible
γ_t = relative shadow value of K assets
(γ = 1 if depreciation correct, investment strategy optimal, and no adjustment costs).

Typical firm's balance sheet

Assets (denominator)	Liabilities (numerator)
Property, plant, & equipment	Common stock
Inventories	Preferred stock
Investments in other firms	Long term debt; bonds
Short term financial assets; cash; receivables	Short term debt; bank loans; payables
Good will; booked investment in intangibles	Subordinated debt; other financial claims
Intangibles not on balance sheet	Owner's equity (residual)

What belongs in the value eq?

- *Only* the assets (resource base) of the firm
  - Physical capital (A)
  - Knowledge capital (K), including IT capital such as software
  - Purchased intangibles (I)
  - Reputational capital, brand name value (stock of advertising)
  - Human capital, to the extent that it is not captured in wages
  - Other infrastructural capital, such as the existence of a distribution network
- *Not* such things as growth in sales or profitability unless they are used as proxies for left-out types of capitals (*similarly for fixed effects?*)

Constructing innovation stocks

$$K_t = (1\text{-}\delta)K_{t-1} + R_t$$

where K_t = knowledge stock at end of period t

R_t = flow of innovation investment during t

δ = depreciation rate of K, usually = 15%

If R grows at a constant rate g over time, then

$$K_t \approx R_t/(\delta+g)$$

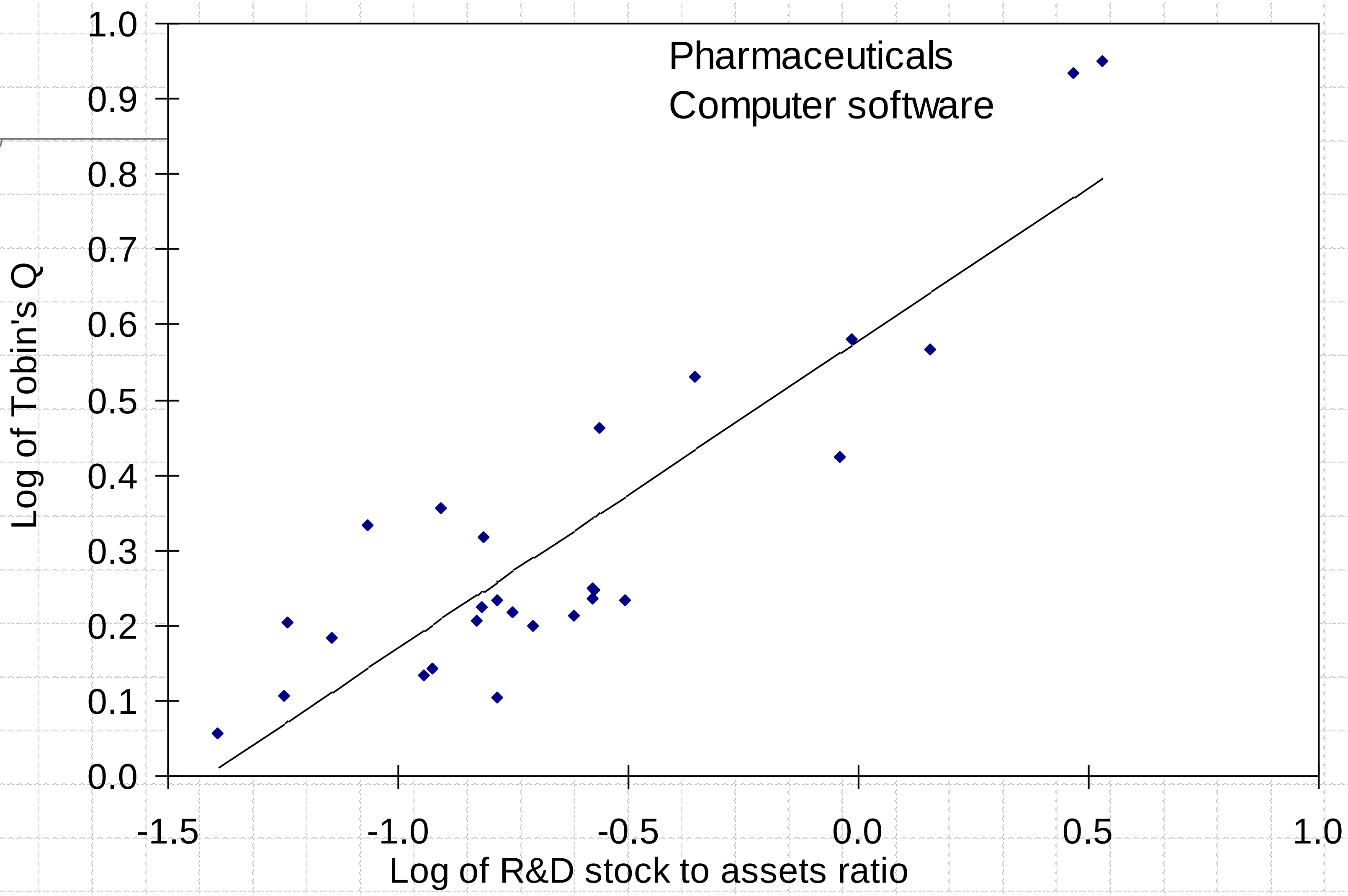
	Used	Truth
g, δ	5%, 15%	5%, 45%
γK_t	$\gamma\ 5R_t$	$2.5\gamma\ 2R_t$

$\Rightarrow$ Low coefficient on K or R may imply $\delta >> 0.15$

Empirical evidence

- Industry aggregates - industries with high Q have high R&D intensity
- Firm-level
  - Functional form?
  - Changes over time

Median Q versus Median K/A by Industry

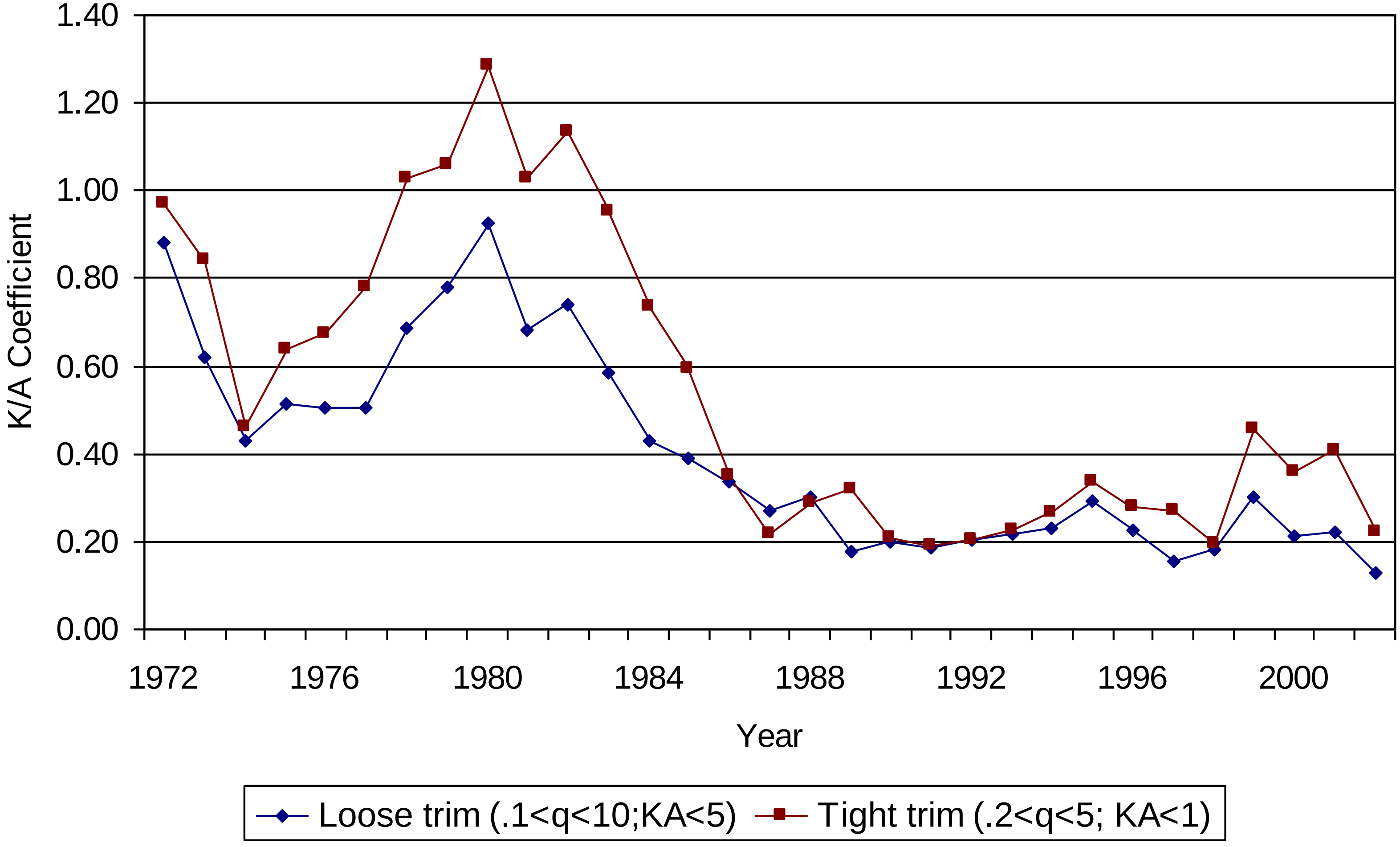


$$\text{LogQ} = 0.58 + 0.40 \log(K/A)$$

Median Q and K/A for selected industries

Industry	K/A	V/A
Pharmaceuticals	3.39	8.92
Computer software	2.92	8.61
Computing equipment	1.44	3.68
Medical instruments	0.96	3.81
Autos	0.18	1.65
Printing and publishing	0.15	2.08
Rubber & plastics	0.15	1.61
Telecommunication services	0.12	2.27
Food & tobacco	0.09	2.16
Primary metals	0.06	1.28
Lumber & wood	0.04	1.14

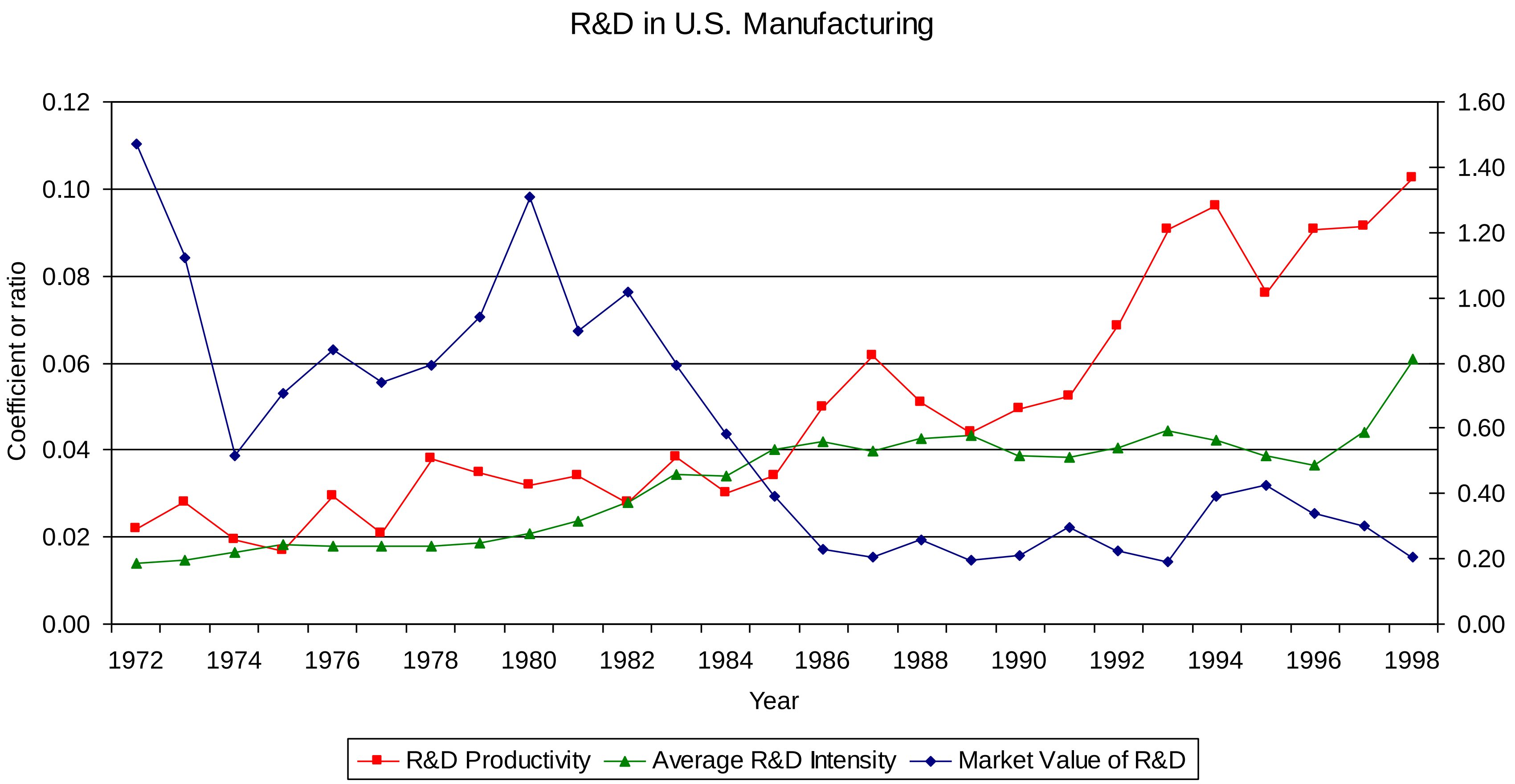
Relative Market Value of R&D Stock - U. S. Manufacturing Sector



A Puzzle?

- Compare changes 1972-1999
  1. Market value of R&D capital using hedonic model
  2. Revenue productivity of R&D capital
  3. Average R&D to sales ratio
- Results
  1. Market value declines during 1980s from 1 to around .2
  2. R&D productivity increases steadily from .02 to .10
  3. Firms investment rate jumps during 1980s from .02 to .04.
- Why?

U. S. Trends in R&D Productivity



Some open questions

- Relationship between firm-level (revenue) productivity and aggregate productivity
- Puzzles
  - Has the productivity of R&D declined?
  - How do we reconcile
    - R&D intensity and R&D growth versions of production function?
    - Market value and productivity versions of rate of return computation?
    - Firm and industry results?
- R&D Stock computation
  - R&D is cumulative, creates "knowledge"
  - Decay of useful knowledge not the same as decay of private returns from that knowledge
  - How to measure and account for this fact in our models?